INFLUENCE OF WATER SATURATION ON THE GEOTECHNICAL BEHAVIOUR OF A LIME TREATED SILT

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ABSTRACT

To reduce soil excess, the refill of trenches for sewage systems with the excavated soil is being developed in Flanders – Belgium. Clayey and silt soils need to be stabilised to allow their application in these refills. A one-year trial program has been executed to evaluate the geo-mechanical evolution of a lime treated soil facing water saturation. A silt, treated with 2 % quicklime was dynamically compacted, at different compaction energies, in four big metallic barrels. The mechanical evolution of the soil was assessed. In parallel, shear box strength tests were carried out on the treated soil before saturation, and after one year of saturation, in order to demonstrate the cohesion and friction angle evolution of the treated soil.

KEY WORDS: LIME / SOIL TREATMENT / SATURATION / STRENGTH EVOLUTION / RECYCLING

1. INTRODUCTION

A large program of sewage collector construction is running in Flanders. In large areas the soils are of clayey or silt nature. These soils cause difficulties in compaction, and therefore they should be removed and replaced by sandy soils for the refilling of the trenches. Stabilisation of these soils is searched by means of lime addition. However, the durability of such stabilisation is questioned. Will there be any softening of the lime treated clay or silt after long time water saturation?

The direct improvement effect of quicklime on wet clayey and silt soils is well known. However, the behaviour of such treated soil facing water saturation, which is frequent in trench applications, is less known and still under discussion. To provide some basic experimental results, a one-year trial program has been executed to evaluate the geo-mechanical evolution of a lime treated soil facing water saturation.

A silt, treated with 2 % quicklime was dynamically compacted, at different compaction energies, in four big metallic barrels. After fourteen days three of them were saturated with water, one was used as reference. During a follow up period of 1 year, regular dynamic cone penetration tests (panda) were carried out. The mechanical evolution of the soil could so be assessed.

In parallel, shear box strength tests were carried on the treated soil before saturation, and after one year of saturation, in order to demonstrate the cohesion and friction angle evolution of the treated soil.

2. EXPERIMENTS

2.1. Program

On request of Lhoist Western Europe the Reyntjens Laboratory of K.U.Leuven has carried out a test programme to determine the behaviour (strength) of a water saturated stabilised soil (clay soil mixed with 2 % of quick lime) over a period of 1 year. The tests carried out include:

- Proctor tests conforming to 50, 100 and 200 % standard proctor energy;
- Shear tests initially and after water saturation for a period of 1 year;
- Cone penetration tests at regular time intervals on saturated stabilised soil samples compacted in barrels at densities corresponding to 50, 100 and 200 % standard proctor energy;
- Cone penetration tests at regular time intervals on an unsaturated stabilised soil compacted in a barrel by 100 % of the standard proctor energy (PANDA-apparatus).

2.2. Test methods

The tests were all executed according to the prescriptions of the following standards:

- Proctor tests: - ASTM D698 - Standard test methods for laboratory compaction characteristics of soil using standard effort.
- Shear tests: - ASTM D 6528 - Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Cohesive Soils.
- Cone penetration tests: - NF XP P 94-105 - Contrôle de la qualité du compactage. Méthode au pénétromètre dynamique léger à énergie variable.
- Methylene blue value: NBN B11-210
- IPI-value: NFP 94-078.

2.3. Materials

The lime used was the commercially available product Proviacal (Lhoist). The granulometry and properties of the silt are given in figure 1 and table 1. Characteristics of the mixture: soil mixed with about 2 % lime is given in table 2. As per ASTM D 2487 the soil can be classified as a fine grained silty - clay soil.

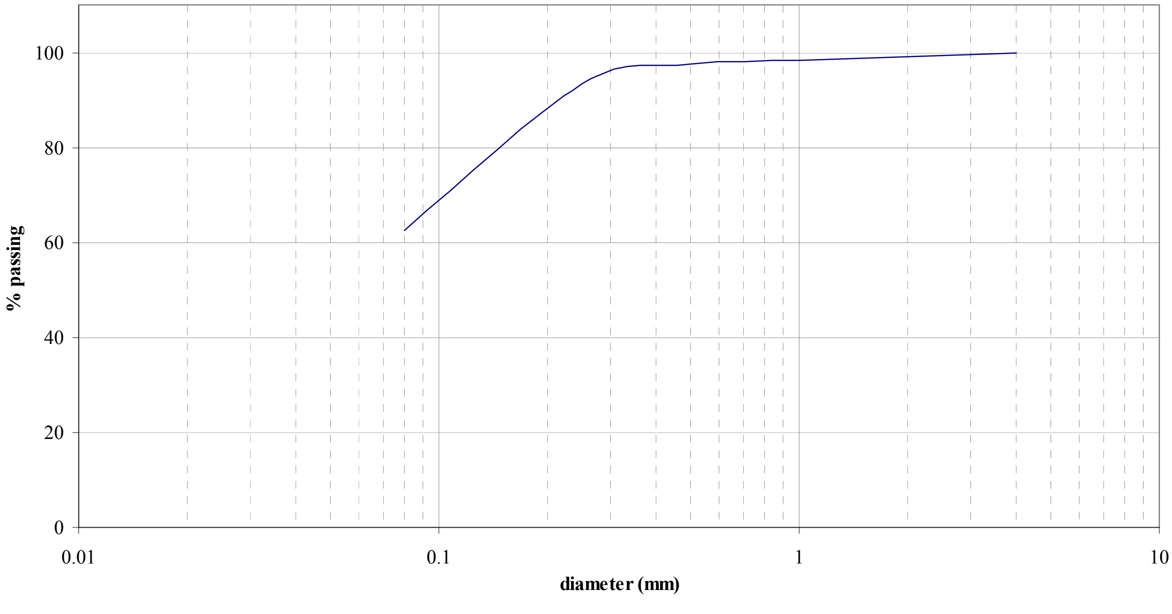

Figure 1 - Grain size distribution curve of the soil

Table 1 - Characteristics of the soil

Density of the soil particles	2586,0 kg/m^3
Methylene blue value	2,5 cm^3

Table 2 - Characteristics of the stabilised soil mixture

ρ (kg/m^3)	1967,0
w (%):	21,4
ρ_d (kg/m^3)	1620,0
IPI (%):	4,7

2.4. Proctor testing prior to filling of barrels

A series of 3 compaction tests were carried out in CBR moulds with each being subjected to different compaction energies (100, 50 and 200 % of the standard proctor energy as given in ASTM D 698). Table 3 gives the characteristics for the 3 compaction tests.

Table 3 - Characteristics of the compaction tests

Compaction test	1	2	3
% of std. Proctor energy	100	50	200
Number of layers	3	3	6
Number of blows per layer	55	27	55
Total compaction energy (J)	1234,2	605,9	2468,4

2.5. Shear tests

Two series of consolidated undrained direct shear tests were carried out under normal stresses of 100, 200 and 400 kPa as per ASTM D 6528. The first series of tests were carried out at the beginning of the test programme and the second series at the end of the test programme with stabilised soil that had been saturated for a period of 1 year. The shear apparatus used has a cross-section of 10cm x 10 cm and a shear displacement rate of 1,0 mm/min was used. The characteristics of the tested samples for the two series of tests are given in table 4.

Table 4 - Characteristics of the shear tests

	Series 1			Series 2		
Test no.	1	2	3	1	2	3
Normal stress (kPa)	100	200	400	100	200	400
ρ (kg/m^3)	1770,0	1866,0	1969,0	2000,0	2040,8	2060,0
w (%)	26,1	26,3	26,3	32,3	32,0	30,9
ρ_d (kg/m^3)	1403,6	1477,4	1559,0	1511,7	1546,1	1573,7

2.6. Cone penetration tests

For carrying out cone penetration tests over a period of 1 year, 4 barrels were filled with stabilised soil to different densities and stored under both saturated and unsaturated conditions. The characteristics of the four test samples and their storage conditions are given in table 5. Saturation was achieved by the addition of water to the three barrels and maintaining a water layer of about 2 cm above the stabilised soil in each of the 3 barrels. The barrel stored under unsaturated conditions was covered to prevent drying of the soil in this barrel.

Table 5 - Characteristics of the four barrels

Barrel numbers:	I	II	III	IV
Compaction energy (% std. Proc.)	100	50	200	100
Density (kg/m^3)	1838,3	1784,2	1877,1	1821,7
Initial water content (%)	24,8	24,6	26,1	26,2
Dry density (kg/m^3)	1473,0	1431,9	1488,6	1443,5
Storage conditions	Saturated	Saturated	Saturated	Unsaturated

The cone penetration tests were carried out in accordance with the schedule given in table 6. The approximate locations of the tests are shown in figure 2.

Table 6 - Schedule of cone penetration tests

Time	Date	CPT tests
Before saturation		
0 days	15 Oct 02	1, 2
14 days	29 Oct 02	3, 4
After saturation		
14 days	13 Nov 02	5, 6, 7
1 month	27 Nov 02	8, 9, 10
3 months	24 Jan 03	11, 12, 13
6 months	24 Apr 03	14, 15, 16
12 months	27 Oct 03	17, 18, 19

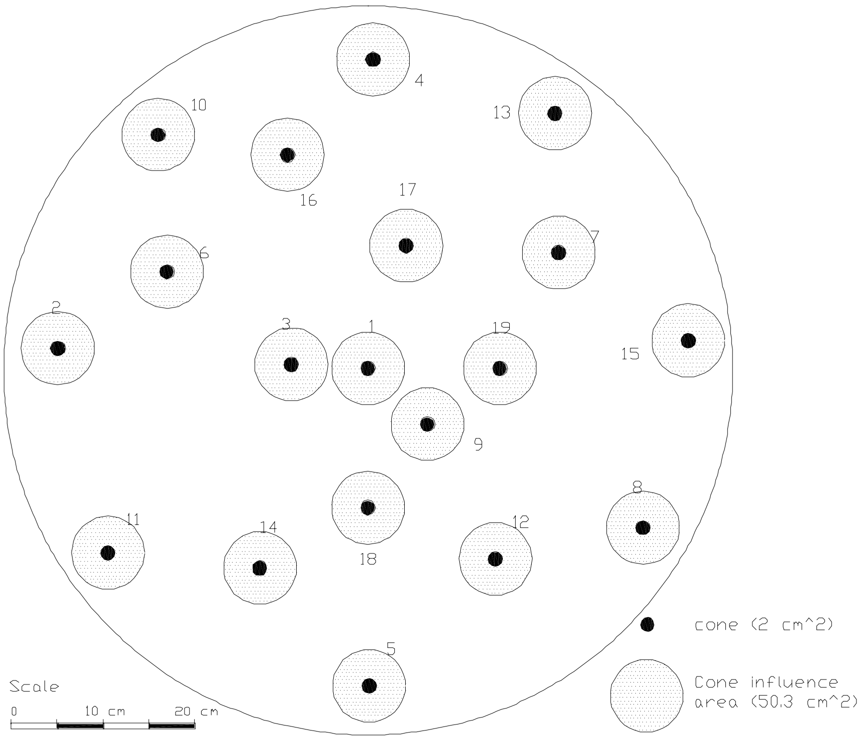

Figure 2 - Location of cone penetration tests in each of the four barrels

3. TEST RESULTS

3.1. Compaction tests

The results of the compaction tests are given in table 7.

Table 7 - Compaction test results

Test	1	2	3
Std. Proctor energy (%)	100	50	200
Wet density (kg/m^3)	1911,6	1891,9	1927,0
Water content (%)	24,9	24,3	24,6
Dry density (kg/m^3)	1530,5	1522,1	1546,5

3.2. Shear tests

The Coulomb failure envelopes derived from the shear tests are shown in figure 3. The shear test results for the two series of tests are given in table 8.

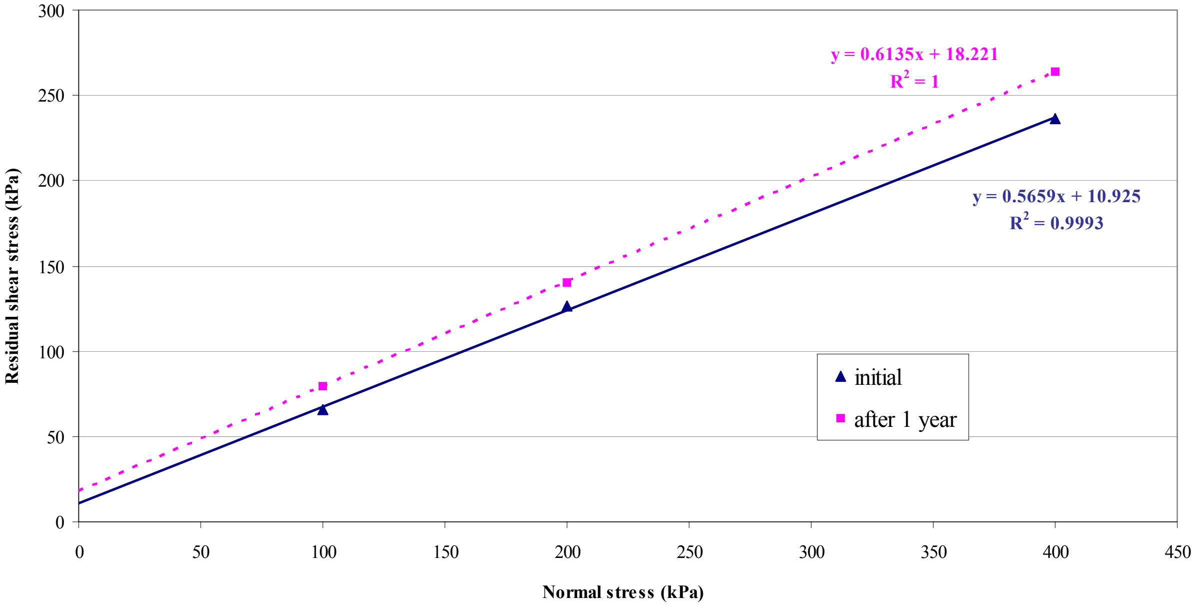

Figure 3 – Coulomb failure envelopes for the two series of tests

Table 8 - Shear test results

	Series 1			Series 2		
Test no.	1	2	3	1	2	3
Normal stress (kPa)	100	200	400	100	200	400
Residual stress (kPa)	65,8	126,7	236,4	79,9	140,5	263,8
Cu (kPa)	10,9			18,2		
Φ_u (degrees)	29,5			31,5		

3.3. Cone penetration tests

As an example the penetrographs for barrel 1 (100 % standard proctor energy and saturated), is shown in figure 4.

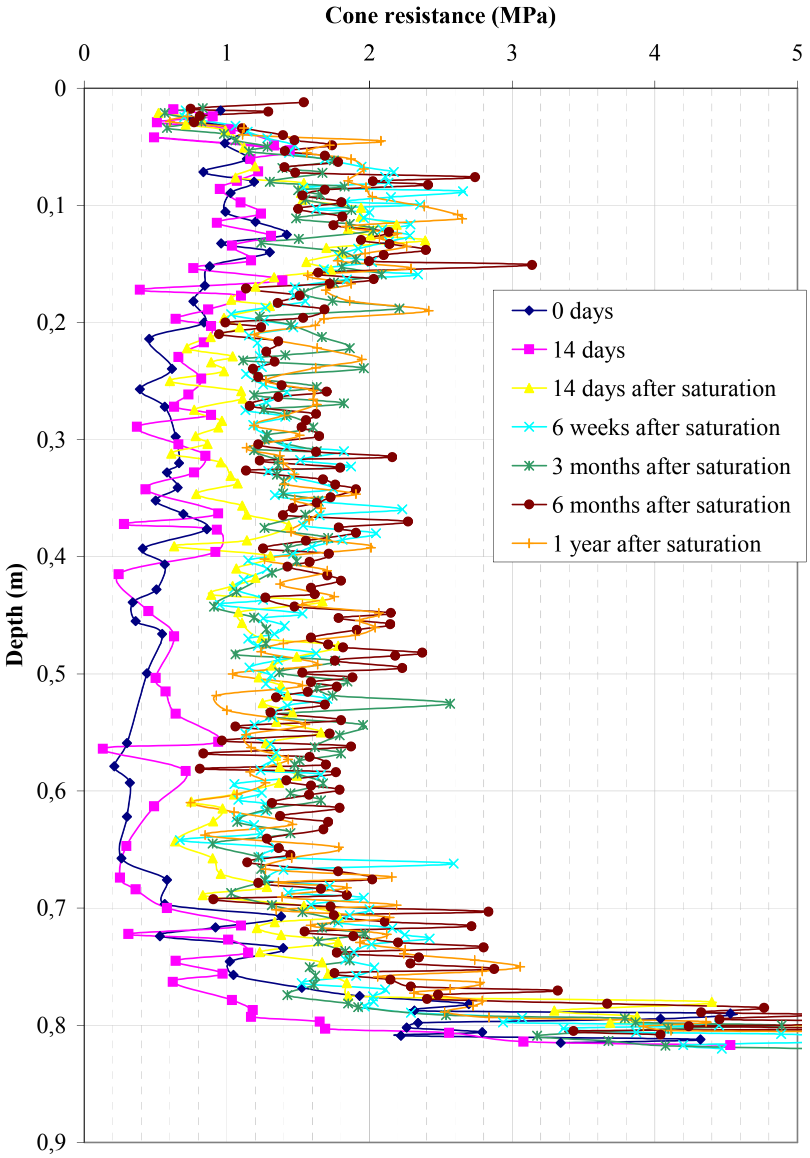

Figure 4 – Penetrographs for barrel 1 (100 % std. proctor energy and saturated)

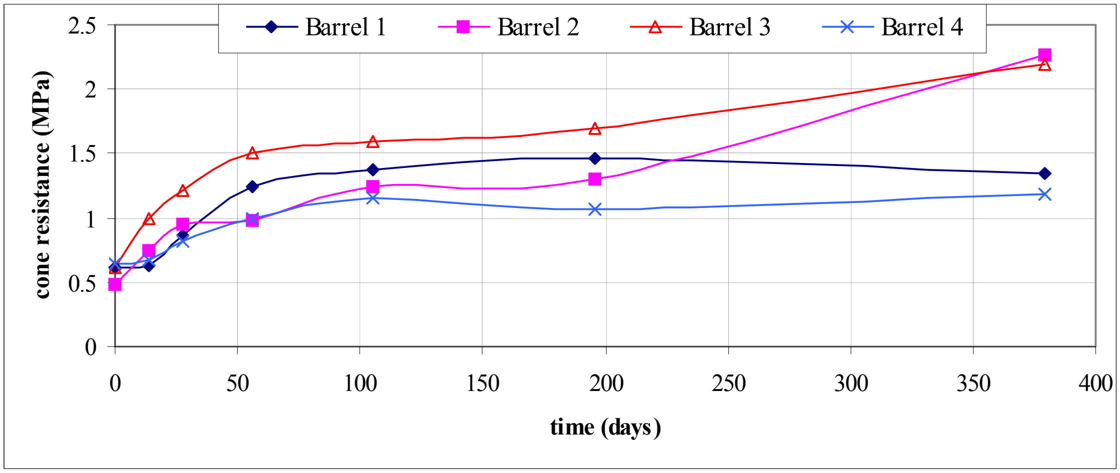

Figure 5 – Evolution of cone resistance with time at a depth of 0,3 m

Figures 5, 6 and 7 show the evolution of the average cone resistance with time for each of the 4 barrels, at three different depths of 0,3 m, 0,5 m and 0,7 m.

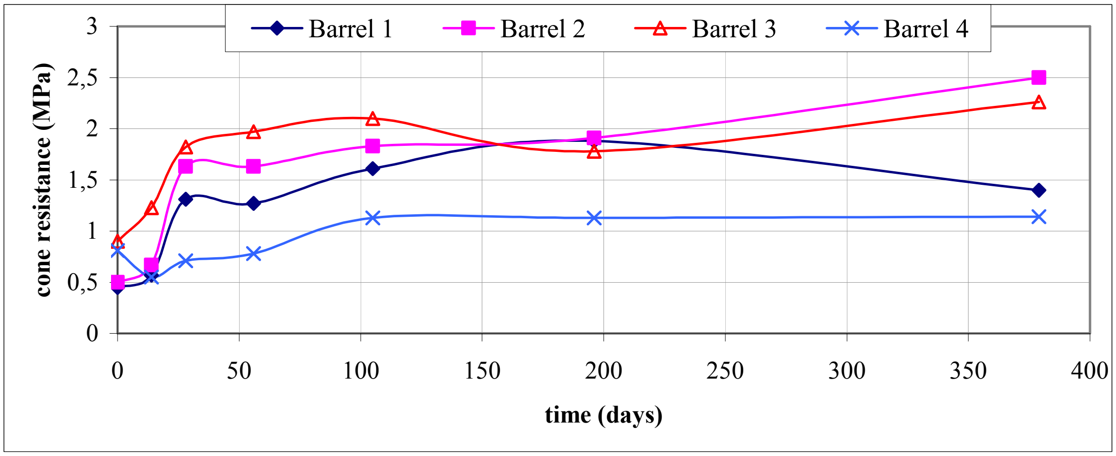

Figure 6 – Evolution of cone resistance with time at a depth of 0,5 m

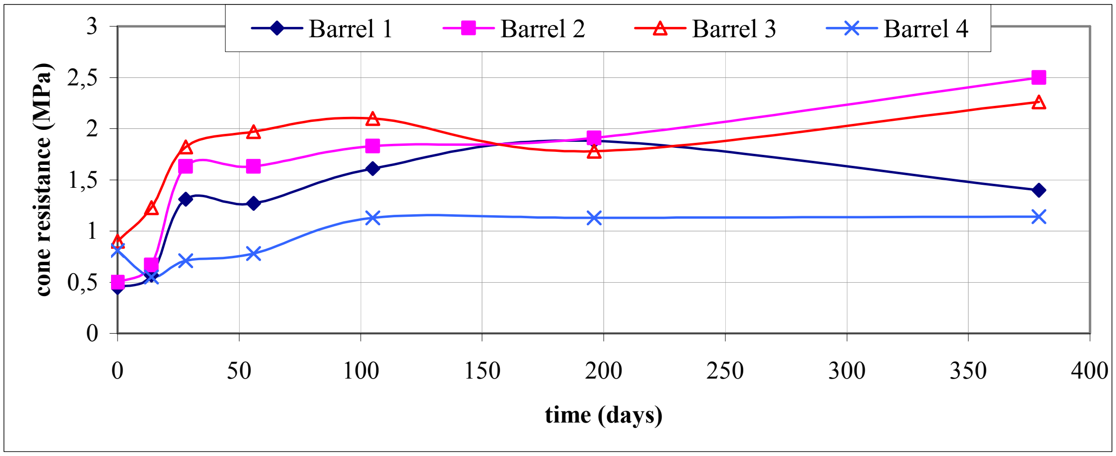

Figure 7 – Evolution of cone resistance with time at a depth of 0,7 m

4. DISCUSSION

The shear and cone penetration tests (see figs. 3, 4, 5 and 6) carried out indicate in general that there is an increase in strength of the stabilised soil with time and that saturated conditions are not essential. From the two series of shear tests carried out; one directly after mixing and the other 1 year after mixing and saturating indicate that the cohesion has almost doubled and the friction angle has slightly increased from about 29,5° to about 31,5°. The strengthening occurs clearly at two different rates. Initially, within the first 50 days, the strengthening occurs rapidly followed by a much more gradual trend thereafter. Even after a period of 1 year strengthening is still continuing.

In general, all four barrels show an increase in cone resistance with time (from about 0,5 MPa to between 1 and 2,5 MPa after a period of 1 year). From figs. 4, 5 and 6 it is clear that barrel 4 exhibits the least increase in strength of the four barrels. This is the barrel that has been stored under unsaturated conditions. Hence, the water present initially in the pores (about 26 % of dry mass) is sufficient to cause strengthening but additional water, leading to saturated conditions, has resulted in a somewhat larger and more rapid increase in strength. However, it is not known what the results would have been if the initial water content was much less than 26 % and what the critical water content is (i.e. the minimum water content to ensure 80 to 90 % of the maximum strength).

The effect of varying degrees of compaction on the rate of strengthening or of the final strengths attained is not so clear. From the latter 3 figures, barrel 3 (200 % proctor energy) in general exhibits, as expected, a higher strength than barrels 1 and 2 both of which have been compacted to a lower degree of compaction. However, barrel 2, which has been compacted using only 50 % of the standard proctor energy, does not follow this trend i.e. the strengths are higher than that of barrel 1 (100 % proctor energy). The cause of this is unknown and should be further investigated and may be due to one or more factors given below.

In interpreting the results the following should be taken into consideration:

- the dry densities of the soil compacted in the barrels were less than the values obtained from the standard proctor tests carried out in the laboratory due partly to the differences in water content and partly to the much larger size and lower stiffness of the barrels;
- due to the employing of a manual compaction method and the large size of the barrels, it is not at all possible to obtain uniform compaction of each layer and in some areas a considerable degree of variation is inevitable. Therefore, tests carried out at the same time but at different locations and depths are likely to show, more often than not, variations;
- the cone resistances measured by the PANDA apparatus are for each blow of the hammer and for the depth of penetration of that blow. Therefore, the values of resistances show much variation and each value does not indicate the exact resistance at that level. Thus the average values over a depth will be a better indication of the variation of the ground resistance and can be readily used for comparison purposes.
- there might be an interaction between strength of the soil, obtained by compaction only, and the presence of added burned lime, which hydrates (and expands) afterwards. However, the lime content is small, compared to the pore volume. On the other hand, the way and intensity of mixing will determine the location of the lime in the pores or within the grains. All that will influence the interaction. These effects require further study, as well on micro as on macro scale.

5. CONCLUSIONS

The test program reveals no evidence of weakening or softening of lime treated soils due to saturation and at long exposure times to water saturation. The level of compaction did not show to have a great importance in the tests. This might be due to the elevated water content of the treated soil.

6. REFERENCES

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